Using Benchmarking to Identify Energy Efficiency Opportunity in Cleanrooms; The Labs 21 Approach

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ABSTRACT

Laboratories for the 21st Century (Labs 21) has developed energy benchmarking protocols for use in High Tech Buildings with the objective of improving energy efficiency. Prior energy benchmarking in cleanrooms has identified a wide range of operating efficiencies in HVAC systems. This paper updates previous benchmarking efforts and provides ideas for use of benchmark data to improve energy effiiciency. The benchmark data highlights the fact that some systems are significantly more energy efficient than others in achieving the same cleanliness. These high performing systems can help to identify design and operation strategies for new and existing facilities. The metrics devloped through Labs 21 and prior work can be used to benchmark widely disparate systems. Cleanroom owners can use energy benchmarks to establish efficiency requirements for new design projects. For example, air change rates as measured, vary considerably. The benchmark results suggest that lower airflow using significantly less energy can achieve the desired cleanliness levels. The design concepts that produce highly energy efficient systems are examined in this paper. Better integration of observed best practice concepts into cleanroom design should be possible based upon benchmark guidance.

INTRODUCTION

Integrating energy efficiency improvements in cleanroom HVAC sytems can be a daunting task. There are as many differences of opinion as to whether cleanroom energy efficiency should be persued, and how to best achieve improvements, as there are different system configurations and equipment. Traditionally, the industry has relied on everything from rules of thumb, to sophisticated computational fluid dynamic analyses in the design of cleanroom HVAC systems. Manufacturers of cleanroom HVAC specialty equipment highlight features of their equipment that frequently overlook their energy implications or worse yet, provide conflicting claims. Add to this a climate where speed to market creates schedule pressures for cleanroom operators and designers, it becomes very difficult to know how to set and achieve energy efficiency goals. Knowing what is achievable in the specialized market of cleanroom HVAC systems becomes nearly impossible.

This paper explores the use of a technique that is advocated by Laboratories for the 21st Century (Labs 21) and used in many other business practices and for continuous process improvement. It is possible to apply the findings from energy benchmarking to improve the efficiency and performance of complex cleanroom HVAC systems. By observing actual energy use in operating cleanrooms, trends can be identified and the better performing systems and components can be identified. Armed with this knowledge, an engineer can design and specify improvements to existing systems and set challenging goals for further improvement in new designs. Benchmarking actual energy use through direct measurement gives an accurate picture of the current operational status, but it also can reveal best practices that can be employed to achieve more efficient systems. The systems and strategies that produce better results can lead the way for better performance in retrofit and new construction. By studying the better performing systems, engineers can debunk old myths (“cleaner environments need more airflow”), replicate good designs (low pressure drop systems), and develop innovative methods for further improvement.

A building owner can compare performance against systems of similar cleanliness class to see how his systems compare to others. Metrics which compare the efficiency of HVAC systems and components (such as cfm/kW and kW/ton) are used to avoid the need to compare production metrics (such as kW/product produced) which vary significantly from industry to industry and from process to process within industries.

This paper reviews the results of an energy benchmarking study where energy data was obtained for fourteen cleanrooms. The benchmark results were examined to identify the systems and components that performed well from an energy perspective. Armed with this information, designers and building owners can establish efficiency targets and achieve them by following the concepts that were utilized in the better performing systems.

BACKGROUND

Prior benchmarking work was useful in highlighting cleanroom HVAC systems performance variations. Even though cleanroom HVAC systems typically utilize a large percentage of total building energy (up to 50%) some systems were observed to be operating significantly better than others. The energy benchmarking included large central plant heating and cooling, air recirculation, make-up, and exhaust ventilation.

Recirculation airflows were of particular concern since the measured energy efficiency varies considerably based upon cleanliness class, air change rates, and individual operating preferences. The Institute of Environmental Sciences and Technology (IEST) provides recommendations for air change rates in cleanrooms (IEST 1993) yet measured results drew little similarity to the recommendations. Air change rates exceeded recommendations in some cases and fell short in others, yet all cleanrooms were satisfactory for their intended function. Our understanding is that the recommendations by the IEST were established many years ago from a generally accepted concensus based upon acceptable operating experience, but do not take into account later studies by organizations such as Sematech and MIT. As the benchmark data confirms, it is possible to achieve acceptable performance with significantly lower airflow.

Make-up air requirements, although usually driven by building and fire codes' exhaust requirements, and/or insurance requirements, were usually measured to be far in excess of the minimum. Even though absolute quantities of exhaust and make-up can be debated, minimizing these amounts to achieve a safe environment should be the goal. Benchmark data shows that there is wide variation in the relative air movement efficiency for these systems.

Central Chilled water plants were also a focus of the study. Here, system configurations, chiller efficiency, and supporting system component efficiencies interacted to produce wide variation in overall efficiency.

The benchmark results were reviewed against the characteristics of the individual systems. The better performing systems, and sub-systems, were examined to identify the features that contributed to the improved energy efficiency. These areas each exhibited large variations in energy performance for the same basic function. When reviewing the data, a logical first question was "What are the characteristics of the better performing systems?" followed by "How can professionals in the cleanroom industry better adopt current best practices?"

USE OF ENERGY BENCHMARKS

The metrics advocated by Labs 21 and used in cleanroom benchmarking allow comparisons of widely varying HVAC systems regardless of the design configuration, cleanliness class, or the process occurring in the cleanroom. By examining the data, it is clear that all systems are not created equal. Some systems performed extremely well compared to others serving the same contamination control function. For this paper, several metrics are examined to highlight how benchmarks can help to identify better energy performance. Using this information, cleanroom owners and designers may choose to implement the better performing designs that yield more efficient operation. Although the sample size for benchmarking performed to date is limited, many "best practices" and areas where future improvements could be made were evident

Most benchmarks provide indication of how efficiently the systems are designed and operating. Performance such as cfm per kW (ie. how efficiently air was being moved) was directly measured. In some cases where direct measurement was not possible due to operational concerns, balance reports, EMCS readings, or design data was used. Unlike benchmarks such as W/ft^2 where comparisons of HVAC performance can be masked by process loads or other factors, the metrics examined here facilitate comparisons. Table 1 below illustrates the key HVAC metrics that were examined.

Table 1
Cleanroom HVAC Energy Metrics

Description	Units	Description	Units
Recirculation Air Handler Efficiency	cfm/kW	Chiller Efficiency	kW/ton
Make-up Air Handler Efficiency	cfm/kW	Tower Efficiency	kW/ton
Make-Up Air	cfm/ft^2	Condenser Water Pumps Efficiency	kW/ton
Recirculation Air	cfm/ft^2	Chilled Water Pumps Efficiency	kW/ton
Recirculation Air	Air-changes/hr	Total Chilled Water Plant Efficiency	kW/ton

The most energy intensive systems in the benchmarked cleanrooms were examined. The cleanrooms studied included five Class-10 (ISO Class-4), seven Class-100 (ISO Class-5), one Class-100/1,000 (ISO Class-5/6), and one Class-10,000 (ISO Class-7). Results were analyzed to understand the relative ranges of operating parameters and to determine the reasons for the better performing systems and components. Only the class 10 and class 100 systems had sufficient benchmarks to analyse. At the time of the benchmarking, individual recommendations were made at each facility based upon observations and the work completed up to that time. This review, having the luxury of reviewing all of the data, as well as the previous recommendations, identified several key focus areas. The benchmark data suggests focusing on the measures discussed below as a way to achieve better energy efficiency.

To fully take advantage of benchmark results to identify best practices, a larger sample size is desirable. The database should be large enough to capture the full range of performance of different HVAC systems. Nevertheless, with the limited results to date, it is possible to focus on the better performing systems and draw some conclusions. As designers and cleanroom operators see the comparison to best practices, they will naturally begin to incorporate more efficient designs and/or operate at higher efficiencies.

Benchmark data can be used to highlight retrofit, operational, and new construction opportunity for efficiency improvement. By examining some of the metrics and comparing the performance of a cleanroom to the better performing systems, areas of retrofit improvement can be targeted. For example, chilled water systems that do not take advantage of "free" cooling may exhibit poor efficiency compared to those that do. Other metrics such as the air change rate, may indicate that the existing systems can be operated more efficiently and still achieve desired contamination control. To take advantage of benchmark indicators for new construction, cleanroom owners could specify efficiency targets for key systems. For example, recirculation system efficiency in terms of cfm/kW could be specified as a requirement with reasonable assurance that it could be attained based upon actual measured efficiencies.

DISCUSSION

The following metrics are useful and can point to efficiency opportunity in any cleanroom:

Air change rates (ACRs)

If an operating cleanroom is providing higher air change rates than is necessary to maintain cleanliness and contamination control, a significant amount of energy is wasted. Since fan power is roughly proportional to the cube of the airflow, a small reduction in airflow can yield significant savings.

Figure 1 Measuring air flow to determine air change rates

Airflow as measured in operating cleanrooms varies considerably depending upon design and operating philosophy. By carefully considering the air change rates, cleanroom operators can save energy by providing the optimal airflow necessary for the contamination control situation in the room.

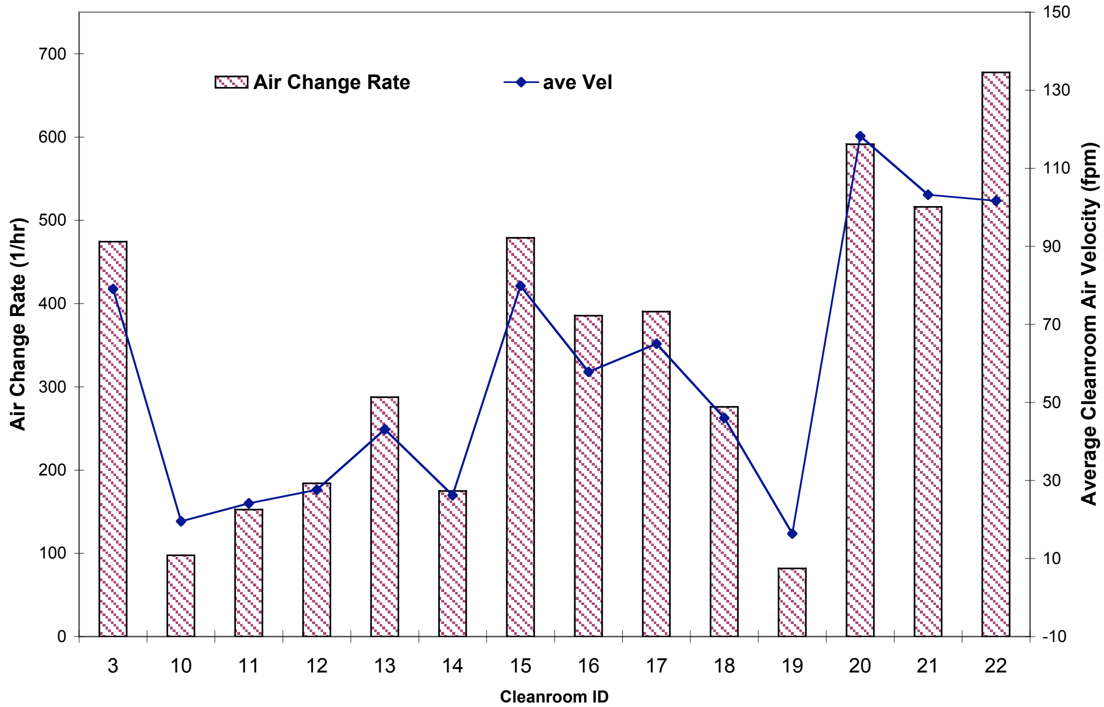

Figure 2. Cleanroom Air Change Rates and Average Velocities

As shown in Figure 2, measured air change rates differed greatly from cleanroom to cleanroom. Yet in each case, the cleanliness and contamination control was adequate for the process occurring in the cleanroom. Other studies by Sematech and MIT concluded that air changes could be minimized with no impact on product yields. Cleanroom professionals can compare their system performance against the measured air change rates and perhaps have indication that air changes can be reduced. For example, by comparing ISO class 5 cleanrooms as in Figure 3 to the recommended air change rates it is clear that reduced airflows are possible with acceptable contamination control results.

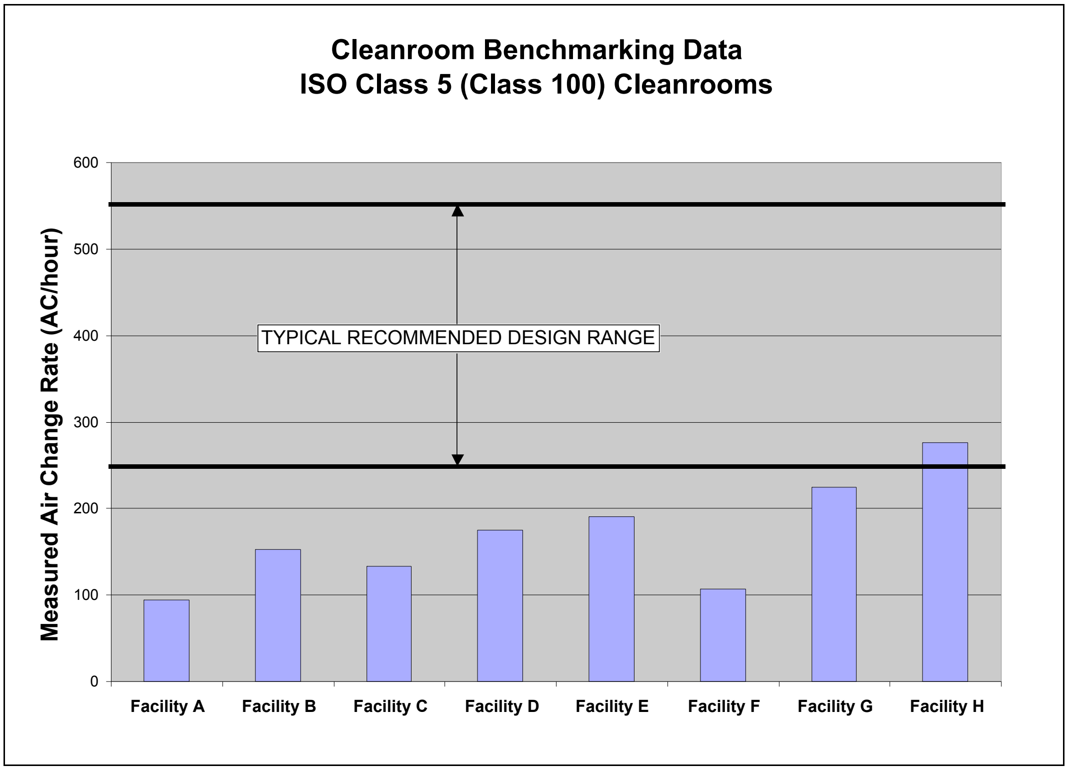

Figure 3 ISO Class 5 Measured air-change rates

Turning down the fan speed (most cleanrooms are capable of doing this) will not only save energy, but will also lower noise, lengthen the life of the fan equipment, and may actually improve cleanliness through less turbulence in the room. In new cleanrooms more carefully selected air change rates can result in smaller fan systems and lower construction costs.

Opportunities for efficiency improvements include:

- Lower air changes rates through different settings in variable speed drives
- Lower air change rates by removing inlet guide vanes fixing variable pitch fan blades on old fan systems and install variable speed drives
- Lower air change rates through the removal of ceiling filters or turning off fans

Cleanroom Air Recirculation (CFM/kW)

Figure 4 Ducted HEPA filters

The benchmark data reveals that efficiency of recirculation systems can vary by factors of 5 or more, for systems serving cleanrooms of the same cleanliness class. Investigating the more efficient systems reveals several considerations to achieve better efficiency. Figure 5 illustrates the range of efficiencies that were measured for these systems.

Benchmarking efficiency of reciculation systems can be tricky. The actual reciculation fan might be efficient but if a large inefficient air handler is used for sensible cooling, the system can be very inefficient. All of the benchmarking data for reciculation efficiency is based on the following formula:

$$\mathrm{Re}\,circ\_Efficiency = \frac{TotalCleanroomAirflow\_CFM}{(\mathrm{Re}\,circ\_Fan\_kW + Sensible\_Cooling\_Fan\_kW}$$

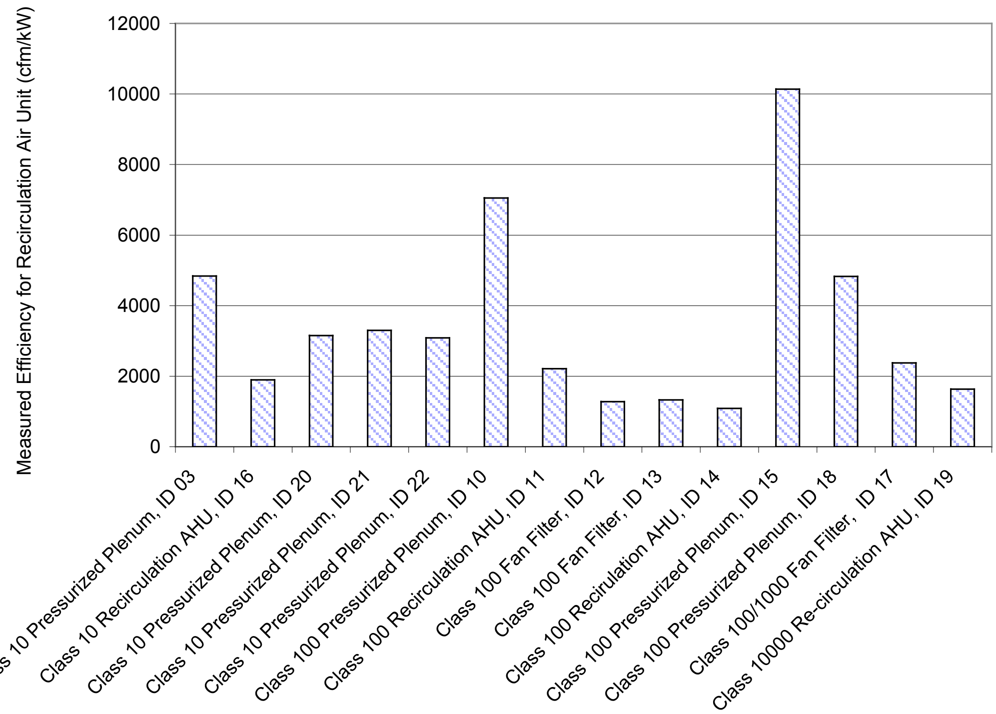

Figure 5 Cleanroom Recirculation Air System Efficiency

System pressure drop is a key concern. Systems designed with low pressure drop throughout the return air path have a clear advantage. This includes, filter coverage, efficient HEPA or ULPA filters, raised floor systems, return air chases, distribution plenums and ducts, air handler face veloctiy, coils, etc. Use of multiple filters also adds pressure drop but may not be necessary.

Another key consideration in recirculation system efficiency as discussed above is the air change rate. Although none of the systems benchmarked in this study were doing it, further efficiency improvement could be obtained by reducing airflow when spaces are unoccupied or otherwise less likely to encounter contamination. Demand controlled ventilation through use of particle counters or control based upon occupancy is possible.

Efficient fans and motors also have an impact upon the overall system performance.

Opportunities for efficiency improvements in recirculation air handling include:

- Low pressure drop air handling path (new construction)
- More efficient fans and electric motors (retrofit or new construction)
- Low power sensible cooling scheme (new construction)

Makeup Air Systems (CFM/kW)

If make-up air handlers (MAH) are running at a higher than average CFM/kW, serveral things might be possible to lower energy use. Lower pressure drop extended surface filters might be possible. Running multiple MAHs in parallel rather than shutting off as a backup will save energy. Also overall energy would be lowered and CFM/kW would be improved if total make up air is minimized. Some opitons for lowering make up air include rebalancing tools, recirculating heat exhaust instead of rejecting it. Some vendors provide add on equipment for lowering tool exhuast.

Opportunities for efficiency improvements in make-up air handling include:
- Low face velocity / low pressure drop air handler
- Low pressure drop filtration stragy
- Running multiple make-up units in parallel
- Optimizing and fine tuning exhuast air quantity

Chilled Water Systems (kW/ton)

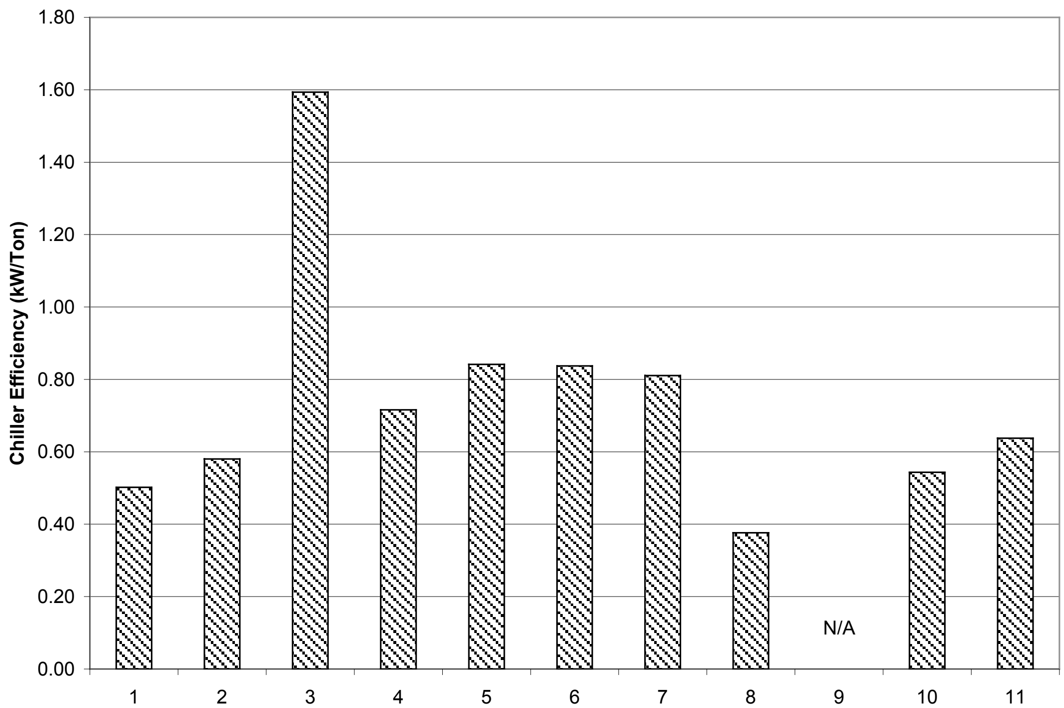

Figure 6. Chiller Performance Comparison

Look at the system kW/ton and see how you compare. Figure 6 shows measured chiller performance and illustrates that the chiller efficiencies in this study vary from 0.4 kW/ton to over 1.6 kW/ton. The efficiency of other system components such as chilled water pumps similarly also vary significantly. If high kW/ton performance is measured, the cleanroom operator should then focus on chiller kW/ton, pumping kW/ton, and cooling tower kW/ton. Each of the components can be compared to other benchmarked systems. These should be at or below the measured averages. Low cost retrofit opportunities typically exist by making pumping improvements and in cooling tower operation. For example, cooling tower fans can be operated in parallel, at reduced speed using a variable speed drive. See slides with pumping example.

Opportunities for efficiency improvements in chilled water systems include:
- High efficiency variable speed drive chillers (retrofit or new construction)
- Low pumping energy schemes such as primary only variable flow chilled water pumping (new construction only)

- Efficient cooling towers capable of low (e.g. 5 deg F) approach temperature (new construction)
- Optimization of chilled water setpoint temperatures (retrofit or new construction)
- Free cooling (water side economizer) (retrofit or new construciton)

DI Water (GPM/kW)

Better distribution control and VSD strategies are possible in DI systems if the benchmark number is high. Also adding VSDs to RO pumps and opening valves can improve the benchmark. Running filters or polishers in parallel are another opportunity.

Opportunities for efficiency improvements in DI Water Systems:

- Variable speed drive RO pump (retrofit or new construction)
- Lower pressure drop RO membranes (retrofit or new construciton)
- Variable speed drives on DI water recirculation pumps (retrofit or new construction)

CONCLUSIONS

Labs 21 has found that cleanroom energy benchmarking can an effective tool to aid in identifying current best practices in complex cleanroom facilities. The HVAC systems that were benchmarked, had widely varying energy performance which provided insight into more efficient schemes. System configuration, components, operational parameters, and sizing all significantly impact energy performance.

The metrics developed for this project can be used for system or component comparison between different types of cleanrooms. This comparison is possible even though the system design and configuration may be completely different. By analyzing the variation in the data, more efficient practices can be identified. The strategies and configurations resulting in the most efficient operation can then be applied to new designs or retrofit into existing facilities. Large apparent variations in the energy use of systems or components may highlight best practices. For cleanroom designers, this data will current high performing systems and can also lead to new creative energy efficient designs in the future.

Future activity should include obtaining more benchmark data, through additional measured performance and benchmarking using design values for various configurations. As an alternate to collecting physical measurements, design-based values may be more readily obtainable and will provide a degree of comparison. Benchmarks can provide needed guidance to designers and owners in choosing design options and in setting efficiency targets for future projects.

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